Charm elliptic flow in Au+Au collisions at RHIC *

Bin Zhang[a], Lie-Wen Chen[b] and Che-Ming Ko[c]

[a]Department of Chemistry and Physics, Arkansas State University, P.O. Box 419, State University, AR 72467-0419, USA

[b]Institute of Theoretical Physics, Shanghai Jiao Tong University, Shanghai 200240, China

[c]Cyclotron Institute and Physics Department, Texas A&M University, College Station, Texas 77843-3366, USA

Using the perturbative method for the simulation of charmed particles, the dynamical origin of charm quark elliptic flow is studied in the framework of a multi-phase transport (AMPT) model. Besides the expected ordering relative to that of light quarks according to quark masses, charm quark elliptic flow is seen to be sensitive to the parton scattering cross section. To describe the observed large elliptic flow of electrons from the decay of charmed mesons, a charm quark elastic scattering cross section much larger than that estimated from the perturbative QCD is required.

1. INTRODUCTION

Because of their large masses, charm quarks are produced very early and propagate through the quark-gluon plasma formed in relativistic heavy ion collisions. Any modifications of charm quark spectrum thus carry information on the properties of the quark-gluon plasma. Although charmed hadrons are at present not directly observable in central nucleus-nucleus collisions at the Relativistic Heavy Ion Collider (RHIC), experimental data on the transverse momentum spectrum of electrons from their decays have already provided useful information on the interaction of charm quarks in the quark-gluon plasma. For example, the transverse momentum spectrum of these electrons is found to be insensitive to the charm final-state interactions as results from both the PYTHIA model and the blastwave hydrodynamic model are consistent with the experimental data [1]. On the other hand, the large elliptic flow of these electrons is consistent with the prediction of the coalescence model [2, 3] which assumes that charm and light quarks are in thermal equilibrium and have same elliptic flow. In the present talk, we discuss in the framework of the AMPT model [4, 5, 6, 7, 8, 9] the mechanism for the generation of charm quark elliptic flow and the dependence of its value on the charm scattering cross section in the quark-gluon plasma [10].

*Work supported by the U.S. National Science Foundation under Grant No.'s PHY-0140046 (BZ) and PHY-0457265 (CMK), the Welch Foundation under Grant No. A-1358 (CMK), and the National Natural Science Foundation of China under Grant No.'s 10105008 and 10575071(LWC).

2. THE AMPT MODEL

The AMPT model has four components: initial conditions, parton cascade, hadronization, and hadron cascade. For studying charm elliptic flow, we use the version with string melting, in which hadrons that are generated from the HIJING model [11] are converted to partons according to their valence structures with a formation time that is determined by the transverse momentum of the parent hadron, in order to simulate the evolution of the energy stored in initial strings and the effects of particle production from the coherent color field. The space-time evolution of resulting partonic system is modeled by the ZPC model [12], which includes elastic scatterings between partons with a cross section given by the leading pQCD and regulated by a screening mass that is taken as a parameter to adjust the magnitude of the cross section. After the partonic system freezes out, closest quarks and anti-quarks are recombined into hadrons with their subsequent evolution simulated by the ART model [13]. Using parton cross sections 6-10 mb, the AMPT model with string melting can give a good description of measured low transverse momentum particle spectrum [14], elliptic flow [7, 14], higher-order anisotropic flows [15], and the pion interferometry [16].

3. SIMULATION OF CHARMED PARTICLES

Charmed particles are rare particles even at RHIC as only about two pairs are produced in the mid-rapidity region of central Au+Au collisions at available top energies. To simulate charm particles efficiently, we use the perturbative method [17] by introducing an enhancement factor for their production from initial hard scattering, so that each charmed particle carries a probability given by the inverse of corresponding enhancement factor, and neglects the effects due to charmed particle scattering on un-charmed particles. Using the power law parametrization of D meson spectrum measured in d+Au collisions by the STAR collaboration [18, 19, 20], we first generate the transverse momentum distribution of D mesons between rapidity of -2 and +2 with their distribution in the transverse plane according to the positions of initial nucleon-nucleon collisions. The initial phase-space distribution of charm quarks is then obtained by dissociating D mesons into their valence quarks after a formation time given by inverse of the D meson transverse momentum. The charm scattering cross section with other partons in the quark-gluon plasma is taken to be the same as the cross section for collisions between light quarks. Both cross sections of 3 mb, which is similar to that given by the perturbative QCD, and 10 mb that is needed for describing observables related to light quarks, are used in present study. At the freeze-out of partons, charm quarks are combined with light quarks into D mesons according to the coordinate-space coalescence model used in the AMPT model. For the scattering of charmed mesons with other hadrons, their cross sections are simply taken to be the same as the charm-parton cross section as their effect on the charmed meson spectrum is insignificant.

4. RESULTS AND DISCUSSIONS

From their transverse momentum spectra at mid-rapidity, charm quarks are found to approach thermal equilibrium when their scattering cross sections increase. This result

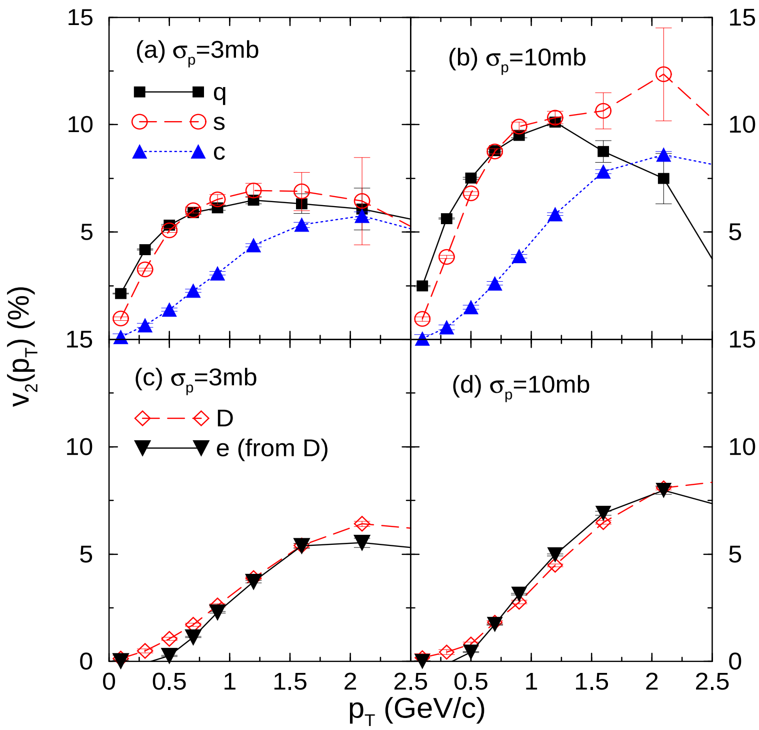

Figure 1. Elliptic flows of quarks, D mesons, and electrons from D meson decay in minimum bias Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV from the AMPT model.

is reminiscent of the transition from the charm spectrum obtained from the PYTHIA to that of the blastwave hydrodynamic model. As in Ref.[1], the spectrum of electrons from the decay of final charmed mesons is not very sensitive to charm final-state interactions and is compatible with experimental data [21] for both cross sections.

For elliptic flows, results from the AMPT model are shown in Fig. 1. It is seen from panels (a) and (b) that the magnitude of charm quark elliptic flow increases with increasing parton scattering cross section. For both parton cross sections, there is, however, a strong mass ordering of quark elliptic flows with charm quark elliptic flow saturating to about the same value at a larger transverse momentum compared with that of light quarks. The elliptic flows of D mesons and their decay electrons are shown in panels (c) and (d). Both are seen to follow essentially that of charm quarks as the momentum of a charmed meson is largely given by that of charm quark when light quarks have only bare masses as in the AMPT model. A larger charmed meson elliptic flow of about 10% at $p_t = 2$ GeV/c is obtained if an isotropic instead of screened Coulomb cross section is used for charm quark scattering as suggested recently in Ref.[22] that charm quark scattering is dominated by the formation of charmed meson resonances in the quark-gluon plasma. To explain the large charm elliptic flow of more than 10% in the available data [23, 24] thus requires effects beyond the perturbative QCD in the quark-gluon plasma.

We have not included in the present study electrons from the decay of mesons consisting

of bottom quark. Their contribution is expected to become important at $p_t > 3$ GeV/c. Also, the effect of radiative energy loss on charm quark elliptic flow, which becomes non-negligible as the charm quark transverse momentum increases, is not considered. For charm quarks with high transverse momentum, charm meson production will be mainly from fragmentation instead of recombination. These effects need to be included for a more complete study of heavy quark elliptic flow at high transverse momentum. Our results are, nevertheless, consistent with other recent studies of charm collective flow [22, 25, 26, 27, 28, 29, 30, 31], i.e., charm elliptic flow is sensitive to charm final-state interactions and a large elliptic flow seen in available data requires a charm scattering cross section larger than that given by the perturbative QCD.

REFERENCES

1. S. Batsouli, S. Kelly, M. Gyulassy and J.L. Nagle, Phys. Lett. B 557 (2003) 26.
2. Z.W. Lin and D. Molnar, Phys. Rev. C 68 (2003) 044901.
3. V. Greco, C.M. Ko and R. Rapp, Phys. Lett. B 595 (2004) 202.
4. B. Zhang, C.M. Ko, B.A. Li and Z.W. Lin, Phys. Rev. C 61 (2000) 067901.
5. Z.W. Lin, S. Pal, C.M. Ko, B.A. Li and B. Zhang, Phys. Rev. C 64 (2001) 011902.
6. Z.W. Lin, S. Pal, C.M. Ko, B.A. Li and B. Zhang, Nucl. Phys. A 698 (2002) 375.
7. Z.W. Lin and C.M. Ko, Phys. Rev. C 65 (2002) 034904.
8. Z.W. Lin and C.M. Ko, Phys. Rev. C 68 (2003) 054904.
9. Z.W. Lin, C.M. Ko, B.A. Li, B. Zhang and S. Pal, arXiv:nucl-th/0411110.
10. B. Zhang, L.W. Chen and C.M. Ko, Phys. Rev. C 72 (2005) 024906.
11. X.N. Wang and M. Gyulassy, Phys. Rev. D 44 (1991) 3501.
12. B. Zhang, Comput. Phys. Commun. 109 (1998) 193.
13. B.A. Li and C.M. Ko, Phys. Rev. C 52 (1995) 2037; B.A. Li, A.T. Sustich, B. Zhang, and C.M. Ko, Int. Jour. Phys. E 10, 267-352 (2001).
14. L.W. Chen, V. Greco, C.M. Ko and P.F. Kolb, Phys. Lett. B 605 (2005) 95.
15. L.W. Chen, C.M. Ko and Z.W. Lin, Phys. Rev. C 69 (2004) 031901.
16. Z.W. Lin, C.M. Ko and S. Pal, Phys. Rev. Lett. 89 (2002) 152301.
17. J. Randrup and C.M. Ko, Nucl. Phys. A 343 (1980) 519.
18. J. Adams *et al.* [STAR Collaboration], Phys. Rev. Lett. 94 (2005) 062301.
19. A. Tai [STAR Collaboration], J. Phys. G 30 (2004) S809.
20. L. Ruan [STAR Collaboration], J. Phys. G 30 (2004) S1197.
21. S.S. Adler *et al.* [PHENIX Collaboration], Phys. Rev. Lett. 94 (2005) 082301.
22. H. van Hees and R. Rapp, Phys. Rev. C 71 (2005) 034907.
23. S.S. Adler [PHENIX Collaboration], Phys. Rev. C 72 (2005) 024901.
24. F. Laue [STAR Collaboration], J. Phys. G 31 (2005) S27.
25. L.W. Chen and C.M. Ko, J. Phys. G 31 (2005) S49.
26. D. Molnar, J. Phys. G 31 (2005) S421.
27. E.L. Bratkovskaya, W. Cassing, H. Stocker and N. Xu, Phys. Rev. C 71 (2005) 044901.
28. G.D. Moore and D. Teaney, Phys. Rev. C 71 (2005) 064904.
29. M. Djordjevic, M. Gyulassy, R. Vogt and S. Wicks, arXiv:nucl-th/0507019.
30. P. Petreczky and D. Teaney, arXiv:hep-ph/0507318.
31. H. van Hees, V. Greco and R. Rapp, arXiv:nucl-th/0508055.